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INT CL⁷ G01L 1/20 , G06K 11/12 11/16
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(54) Abstract Title

Position detector constructed from conductive fabric

(57) A position detector comprises at least two planes of electrically conductive fabric, at least one of the planes incorporating a region 2004, 2006, 2012 of non-uniform conductivity eg mutually orthogonal co-operating conducting strips or threads 2003, 2005, 2011 generating a linear electric field, thereby modifying the detectors response to a mechanical interaction. The strips can be printed onto the fabric, which can be woven, knitted or non-woven eg felt. Electrical connections can be incorporated when constructing the detector, woven into the fabric (1803, Fig.18) or applied as a rivet fastener (1901, Fig.19). Electrical signals can be derived independently by Time Division Multiplexing TMD (Fig.3) via a micro-controller (201, Fig.2) operated circuit (121, Fig.2). At least one of the planes may consist of first and second portions (1206, 1205, Figs.12A, 12B), the first portion having a higher resistance and being more flexible to allow complex curvature (Fig.12B). A second electrical property eg current or resistance can be used to identify additional properties of the mechanical interaction eg applied force, area of contact or orientation of an object.

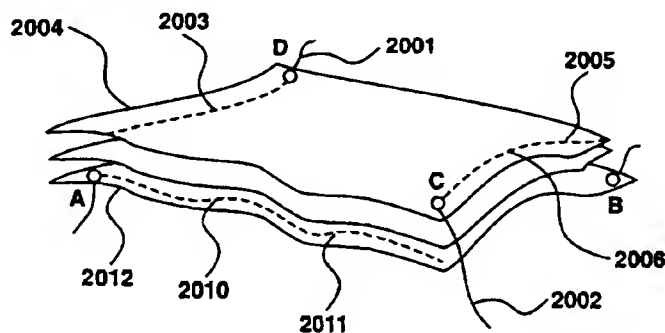
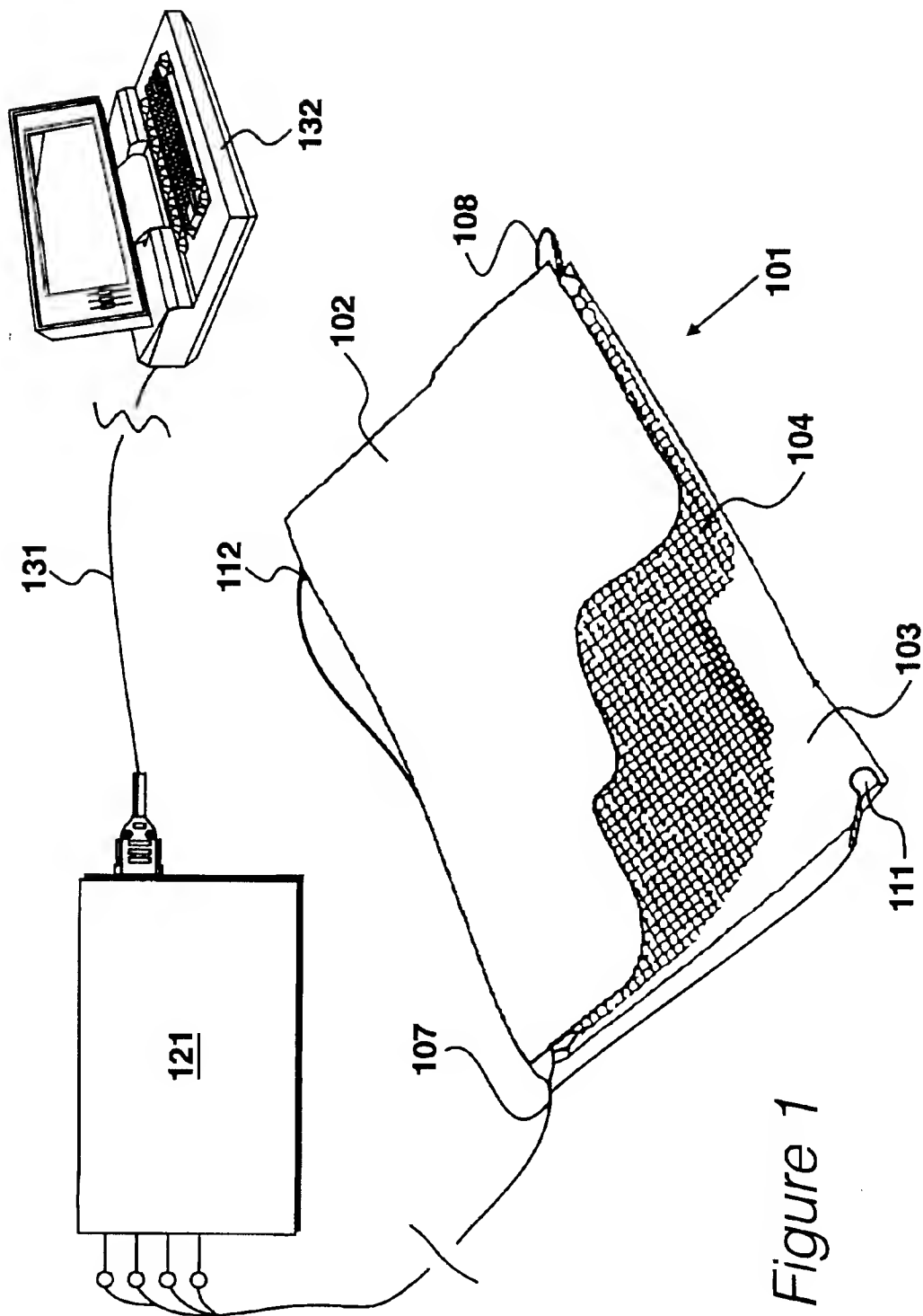


Figure 20

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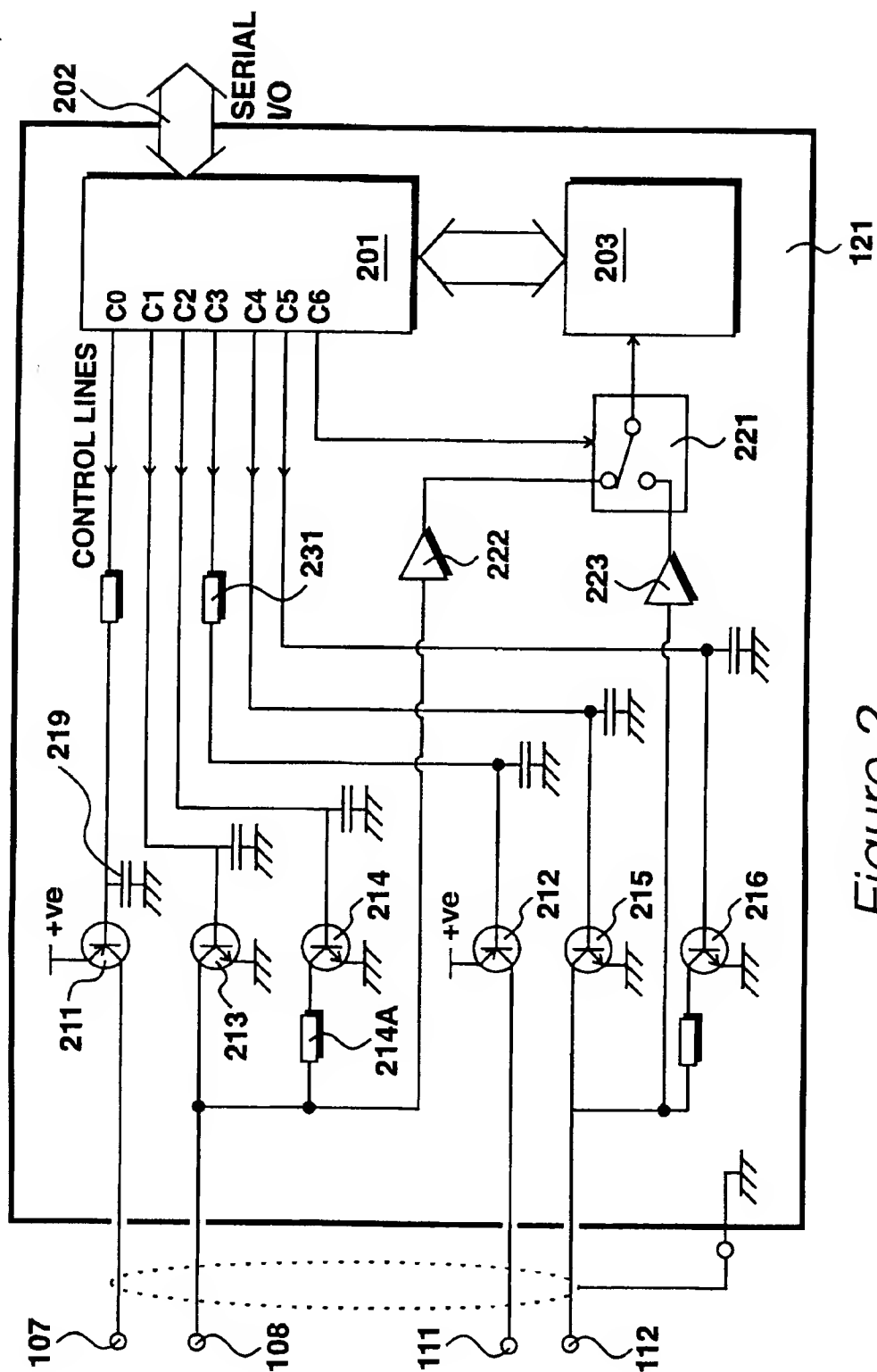
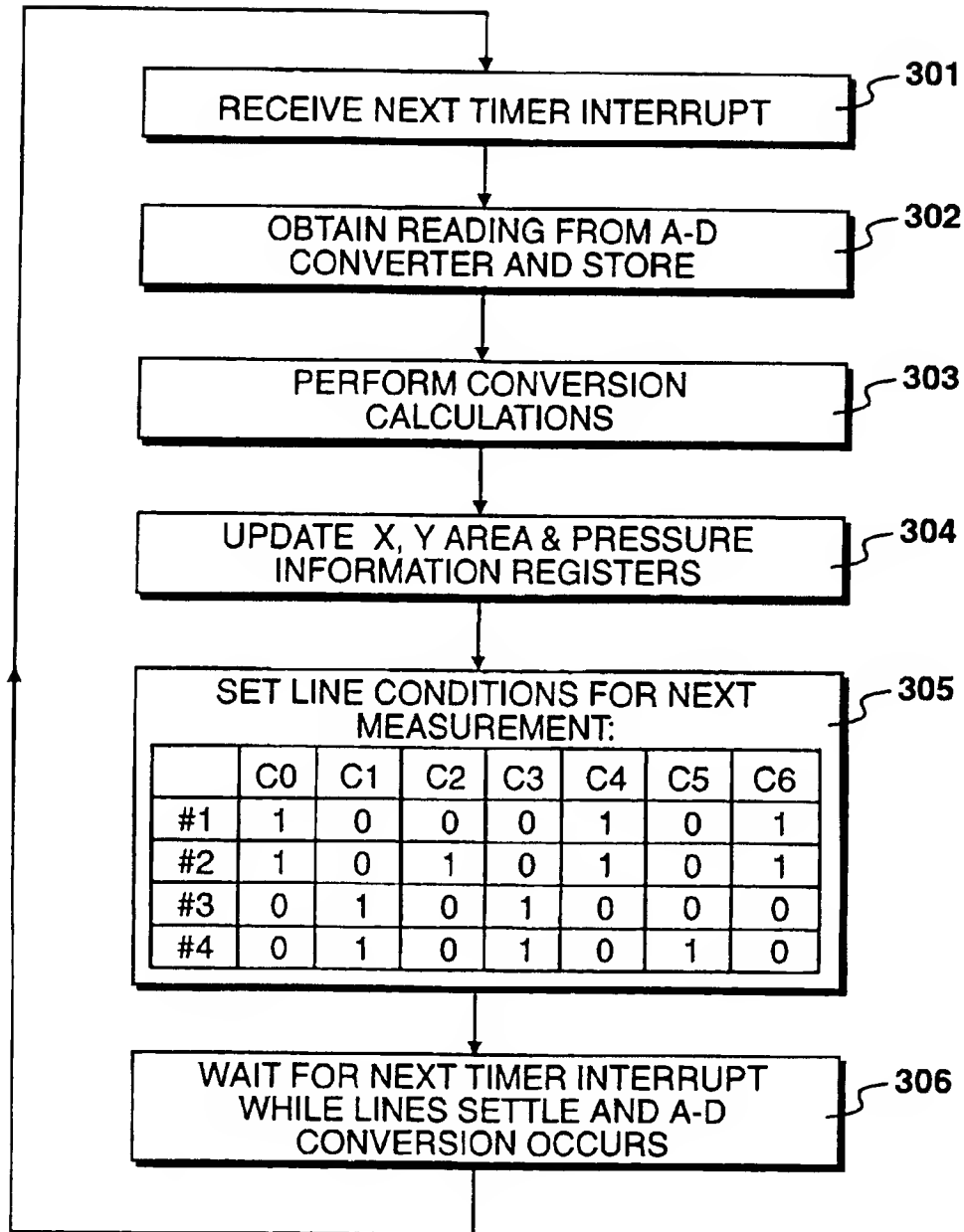


Figure 2

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*Figure 3*

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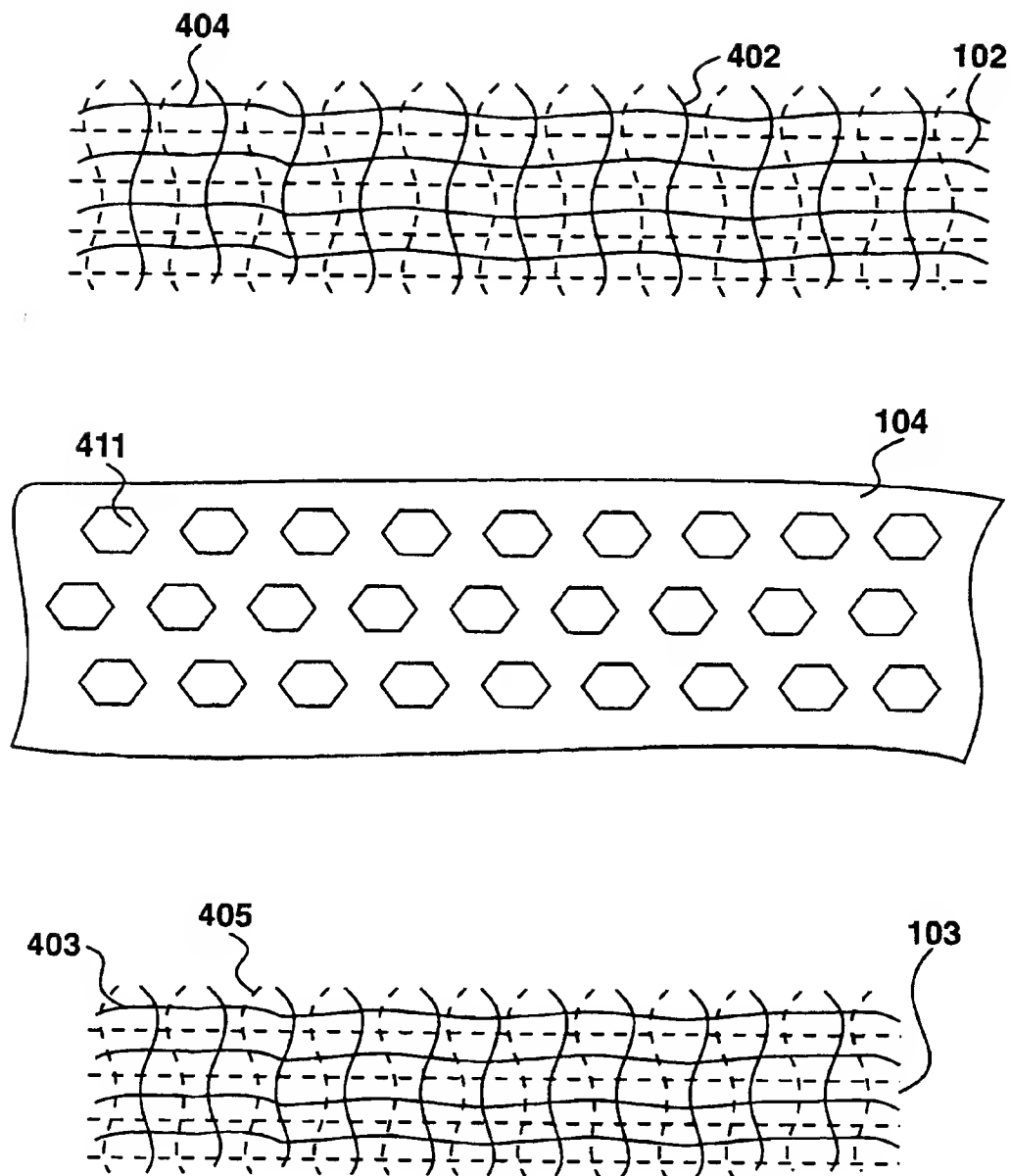


Figure 4

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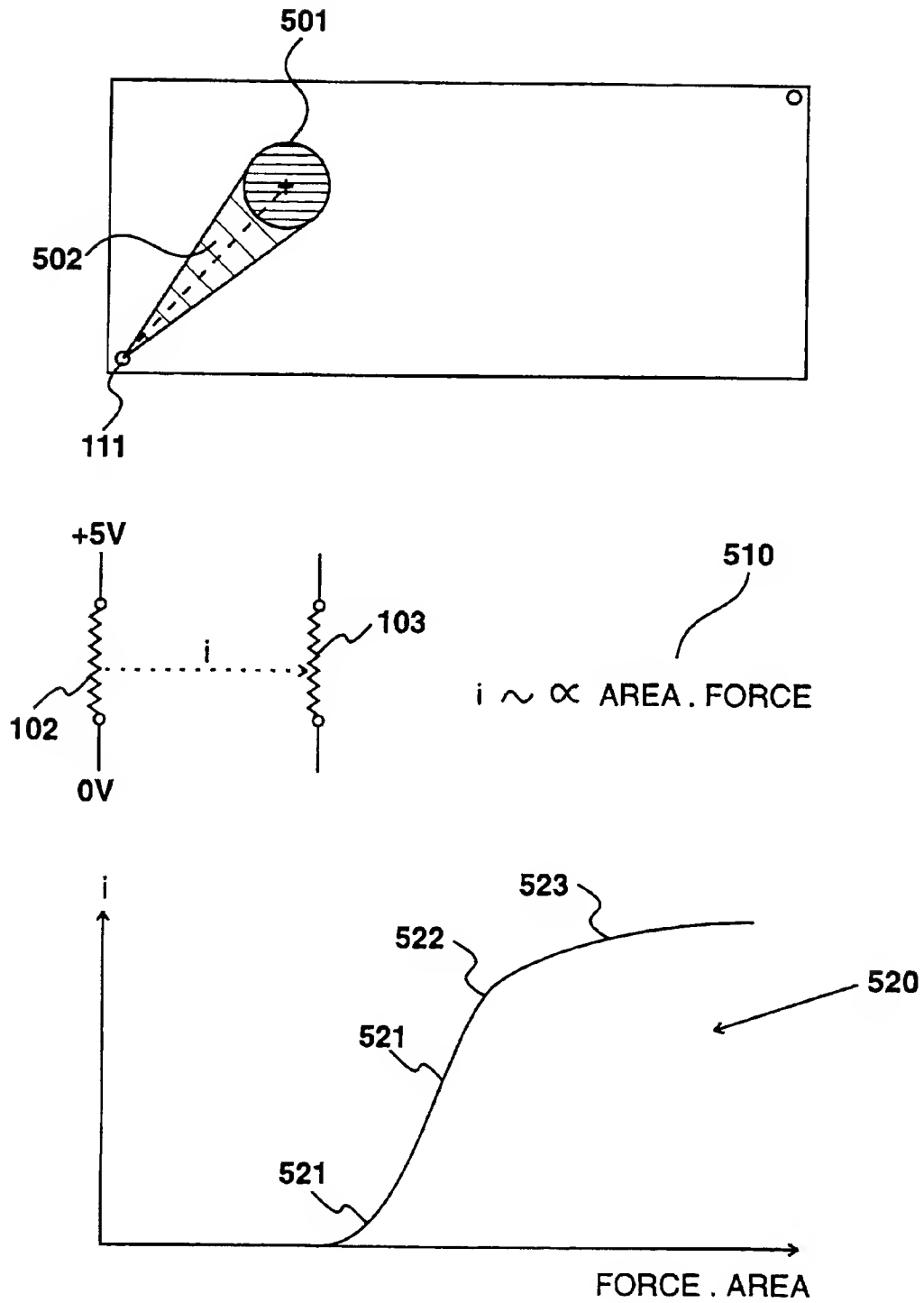


Figure 5

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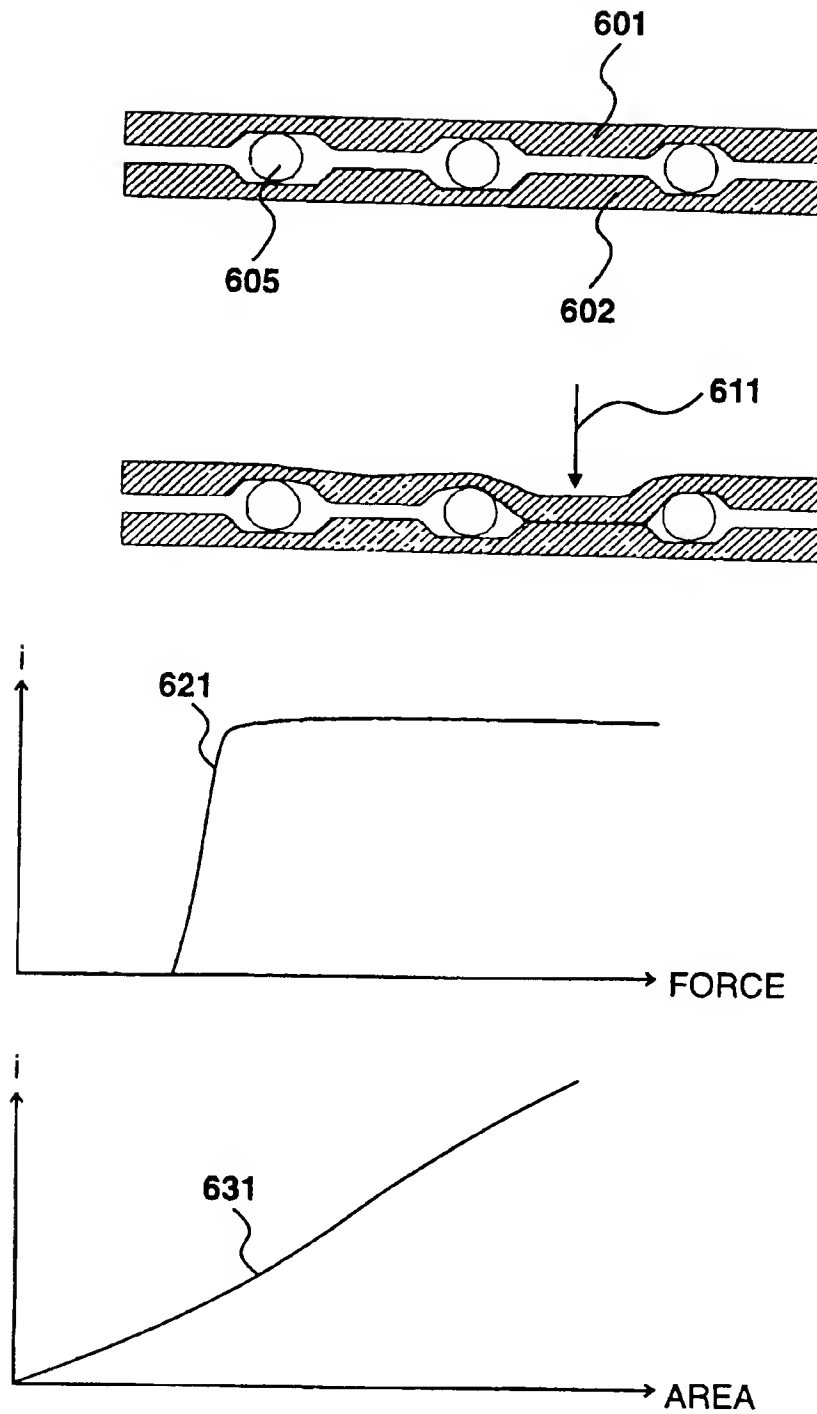


Figure 6

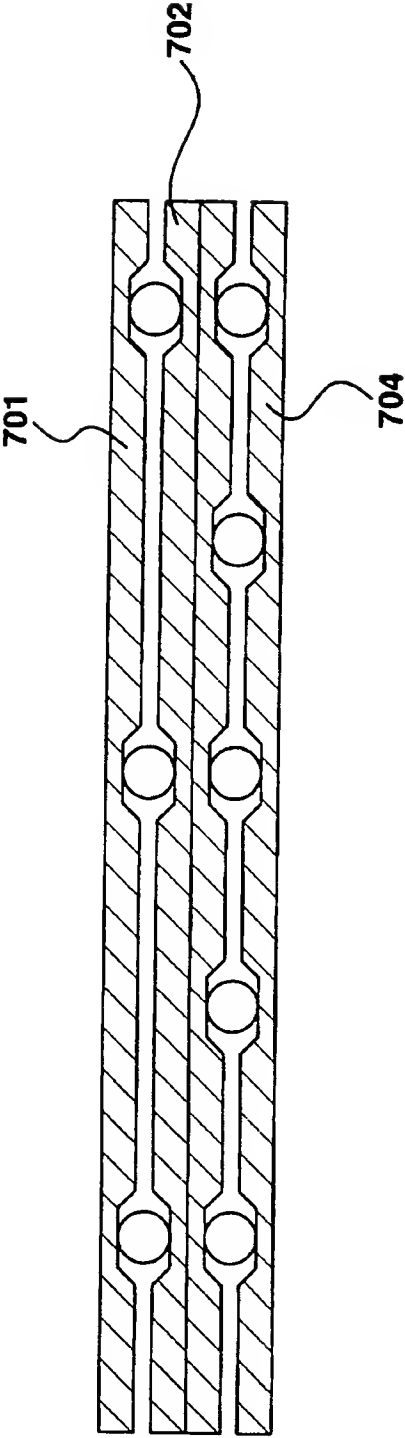


Figure 7

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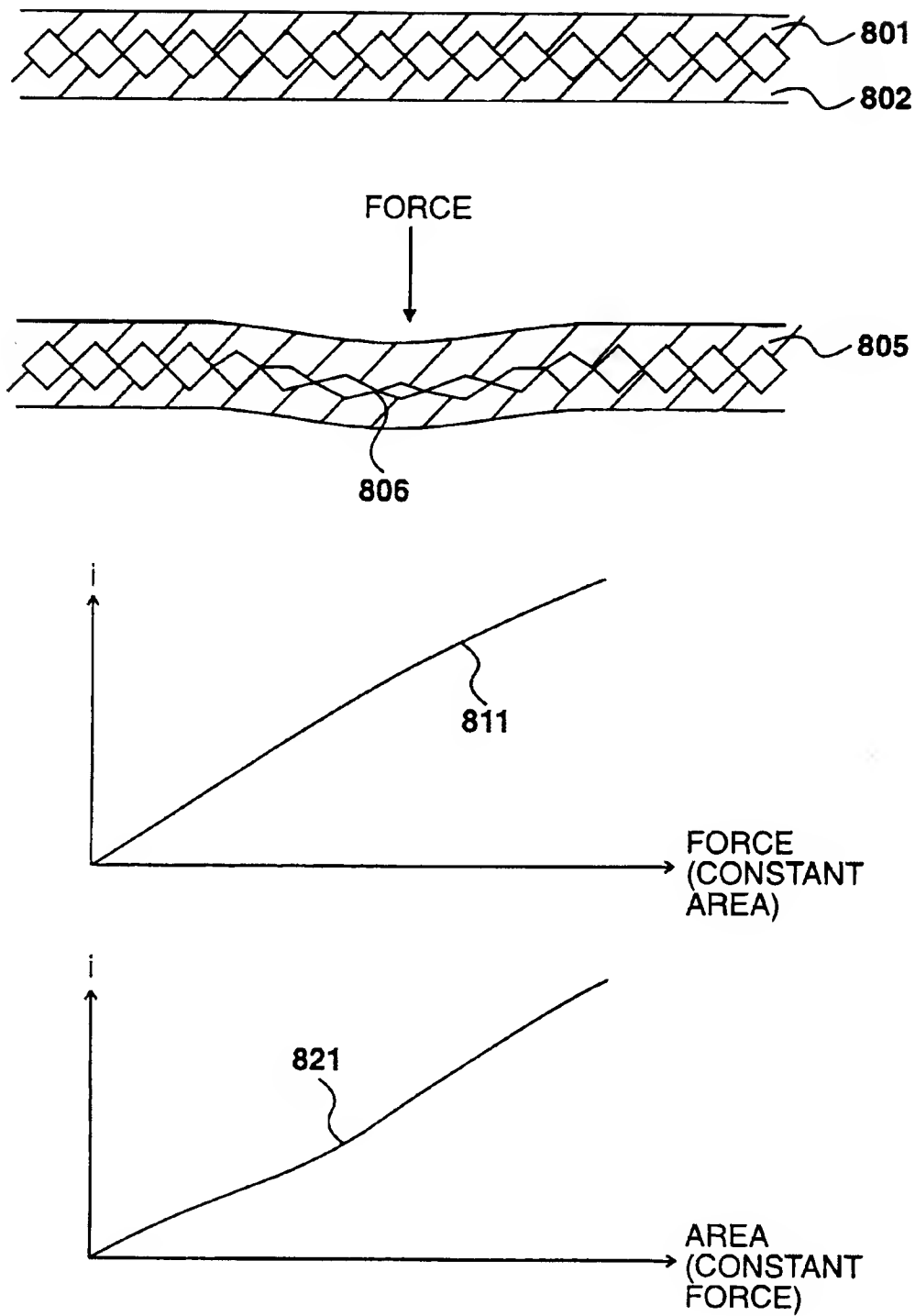


Figure 8

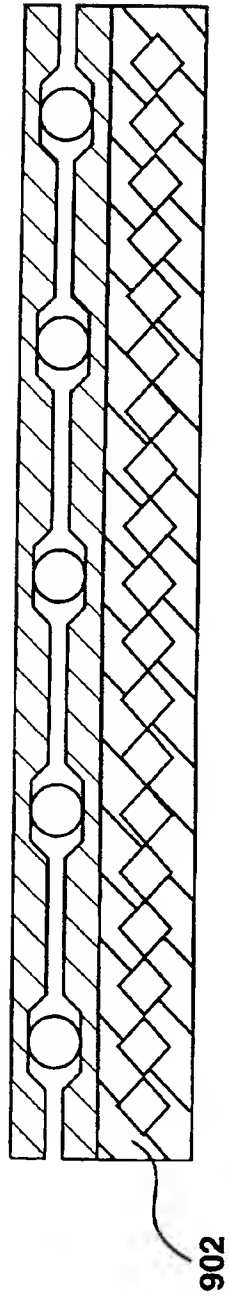


Figure 9

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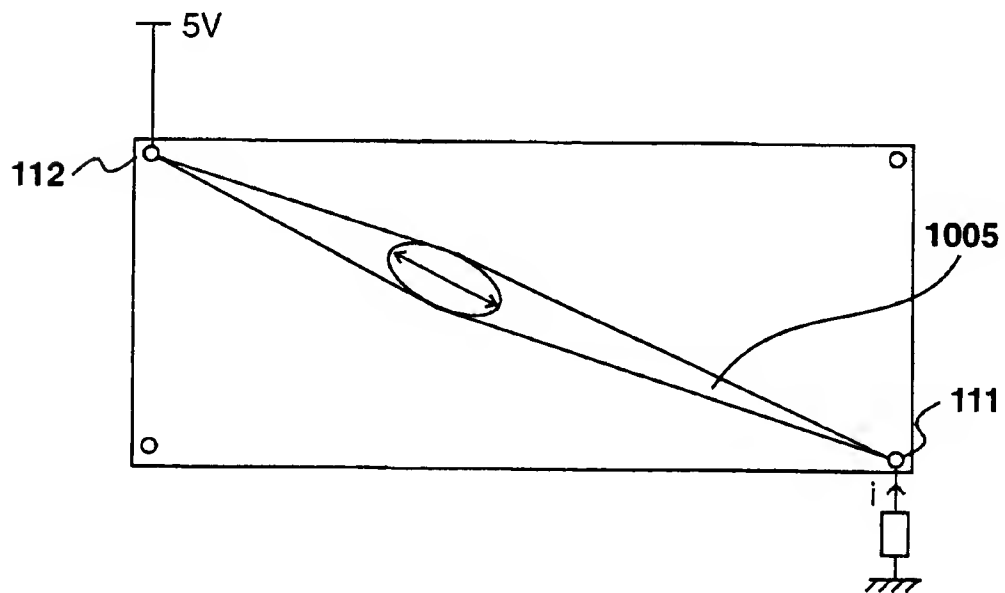
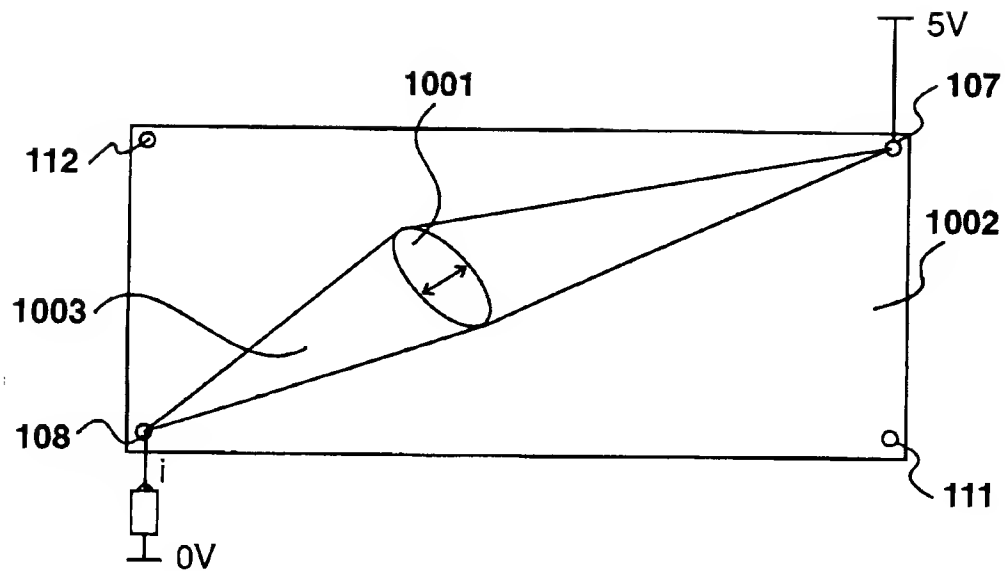


Figure 10

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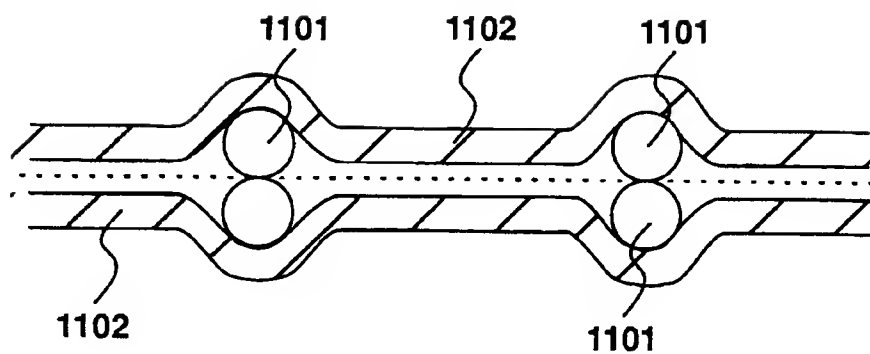


Figure 11A

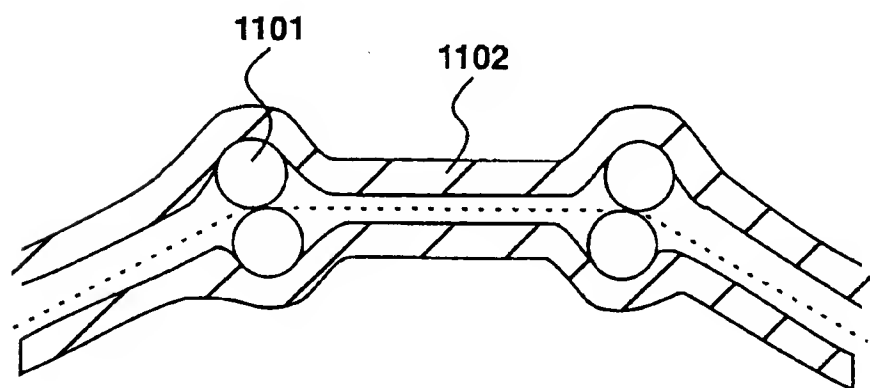


Figure 11B

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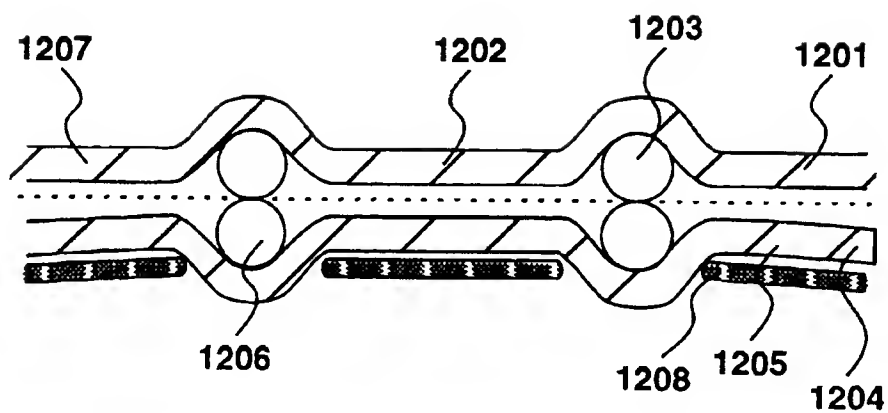


Figure 12A

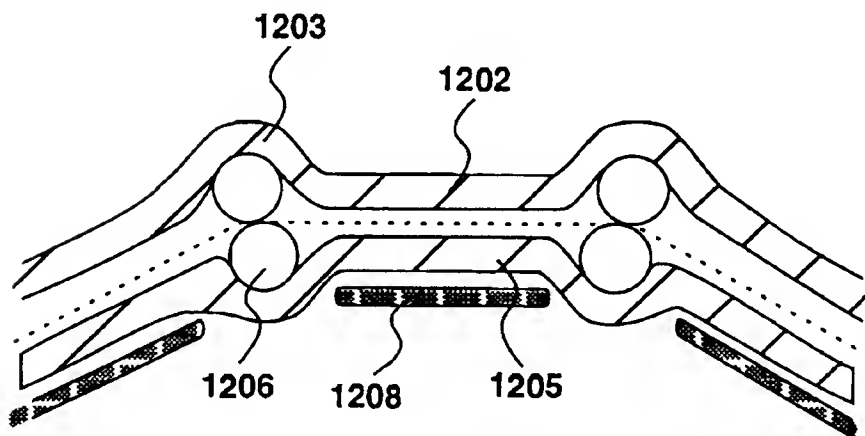


Figure 12B

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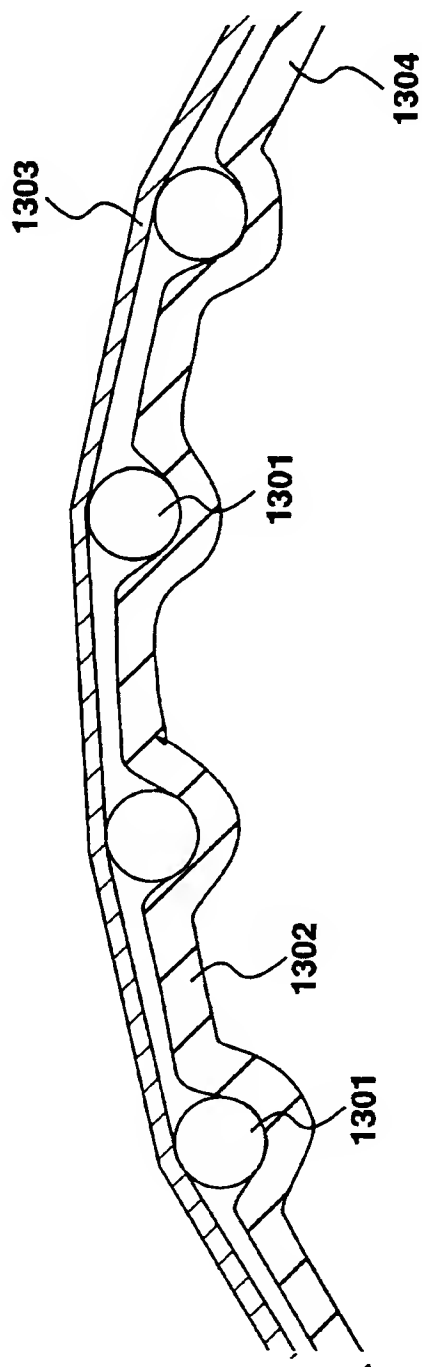


Figure 13

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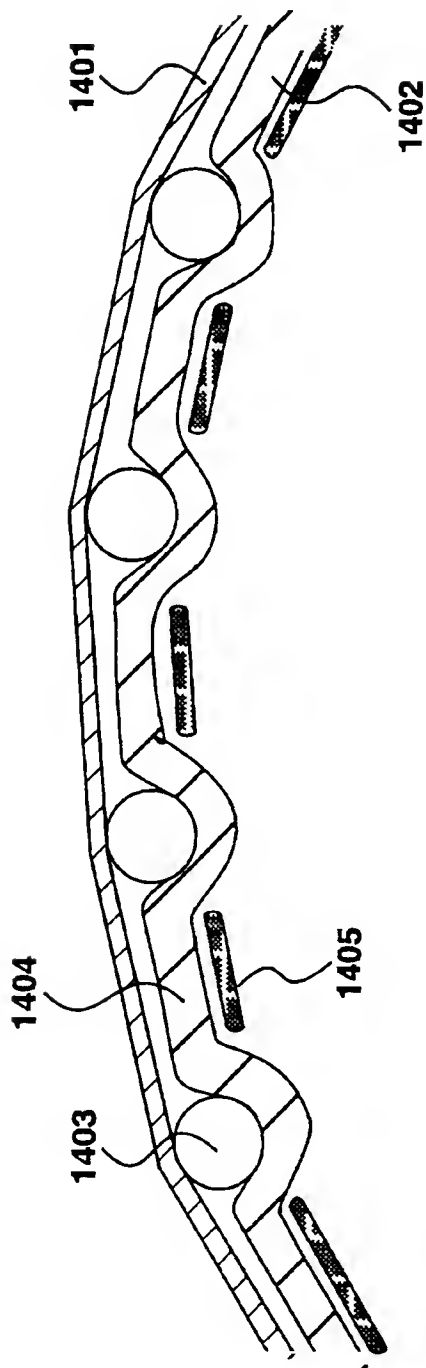


Figure 14

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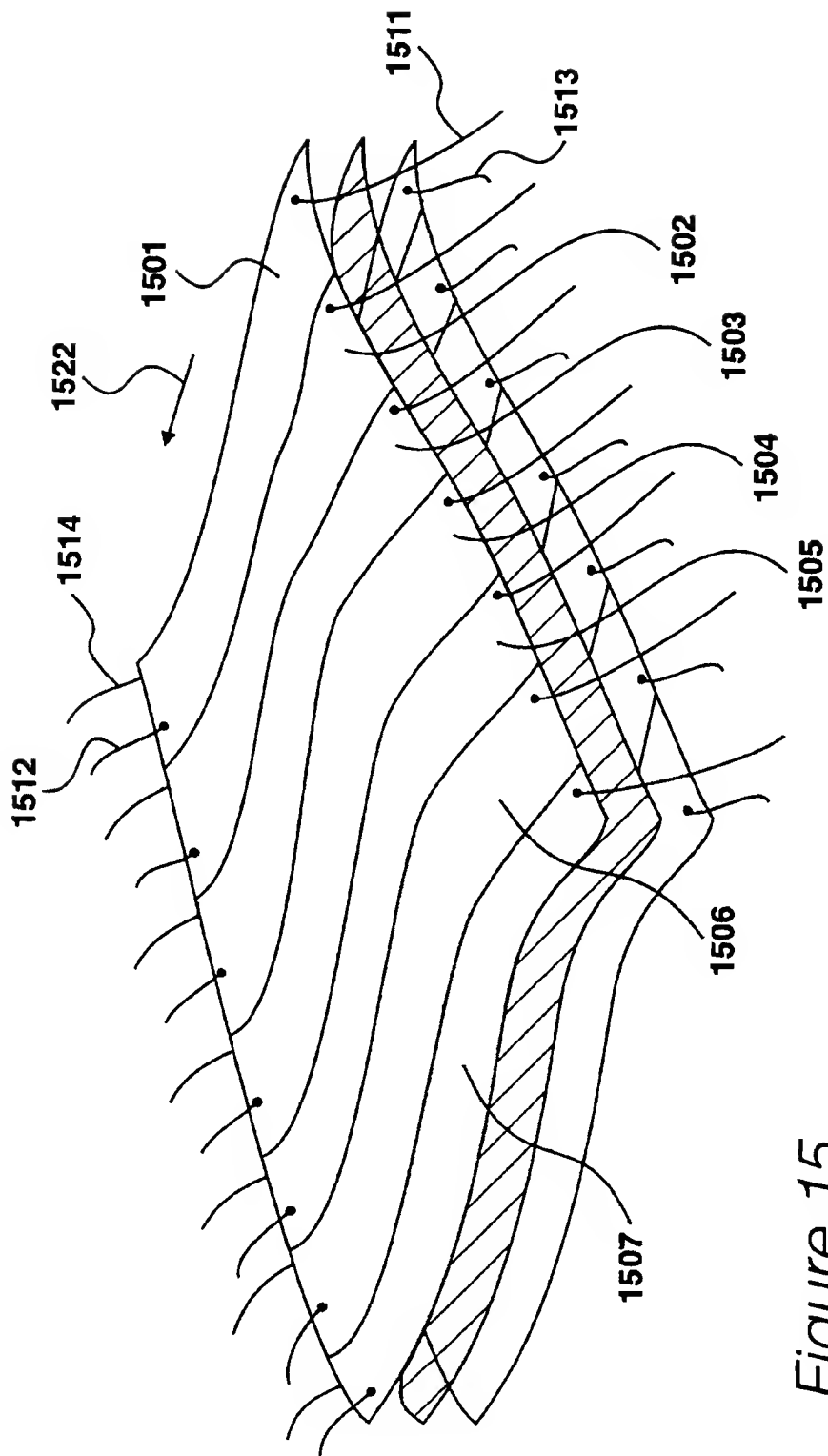


Figure 15

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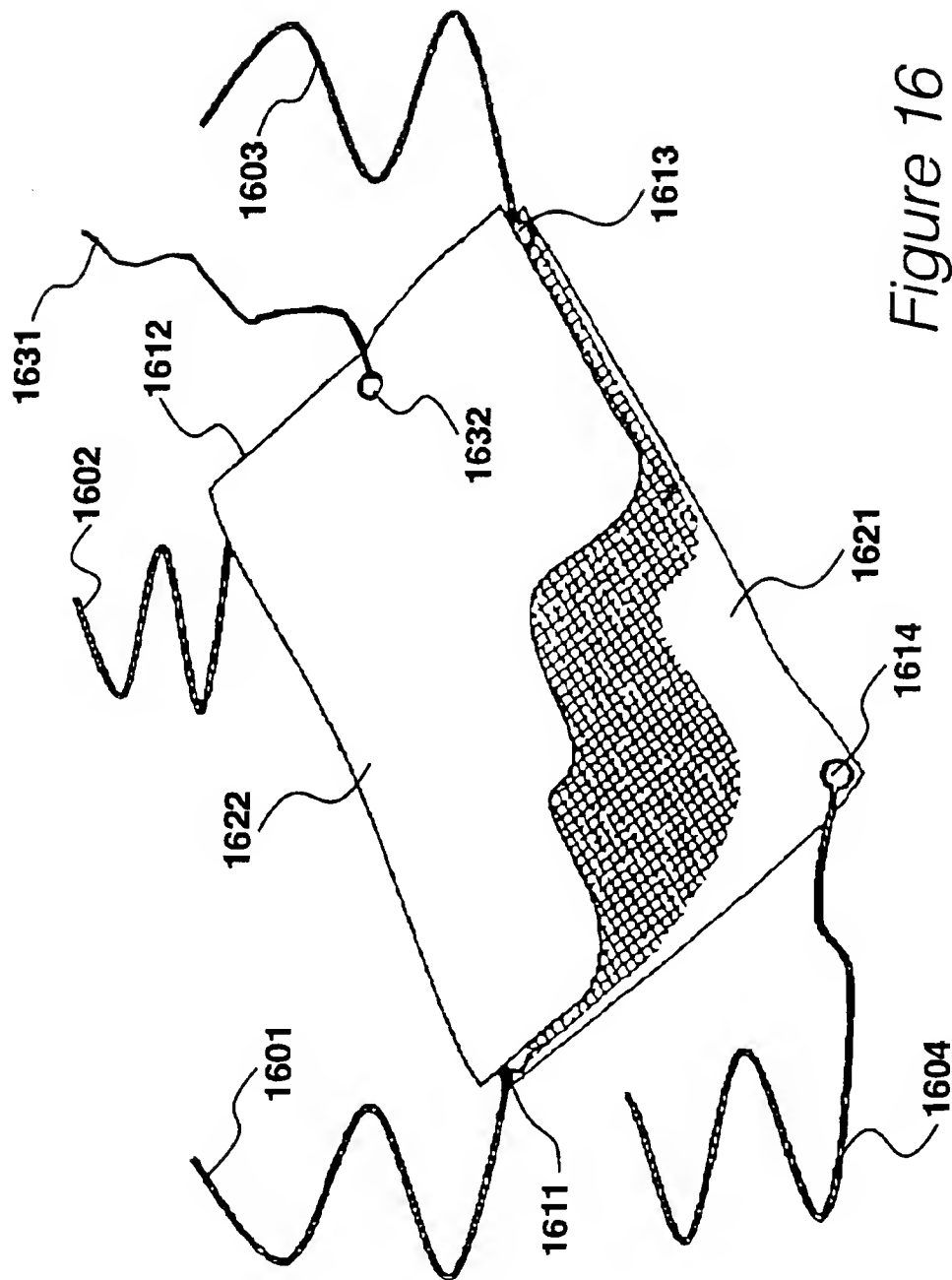
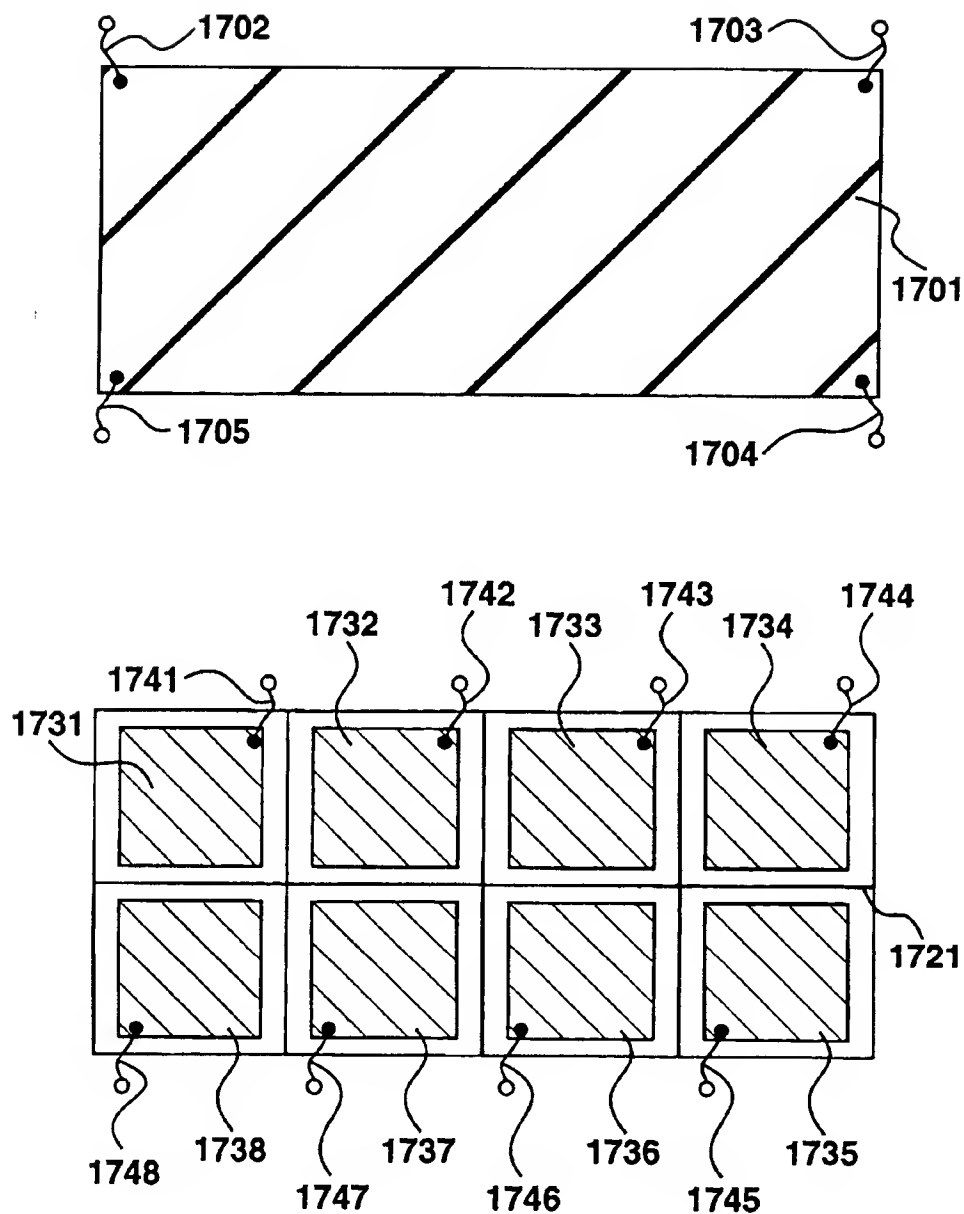


Figure 16

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*Figure 17*

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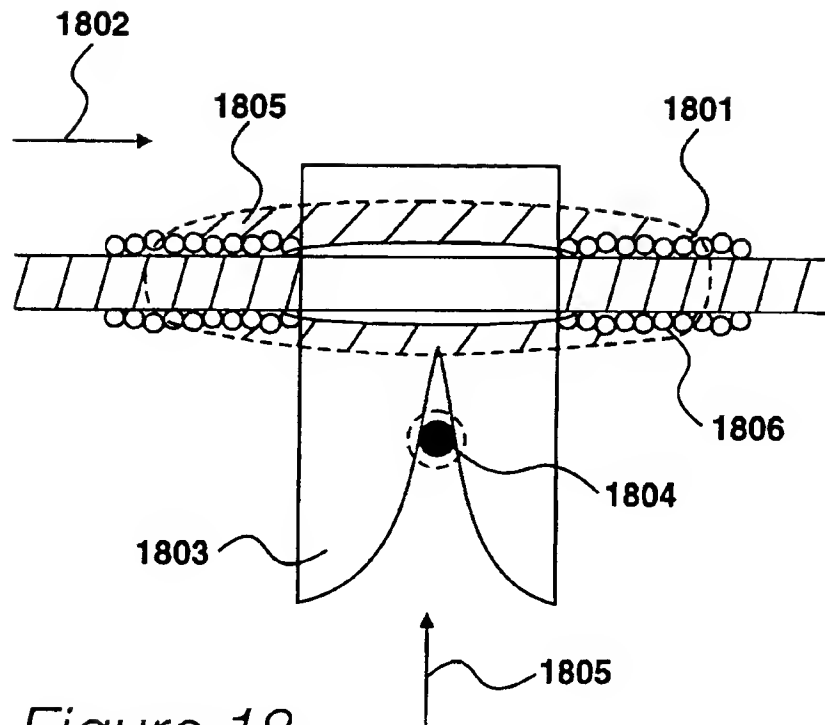


Figure 18

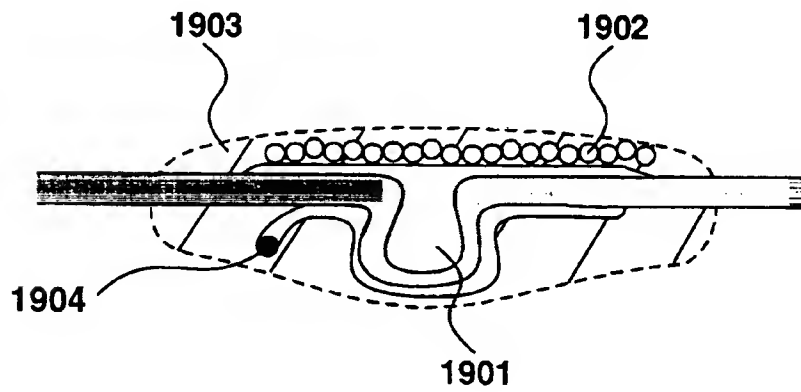


Figure 19

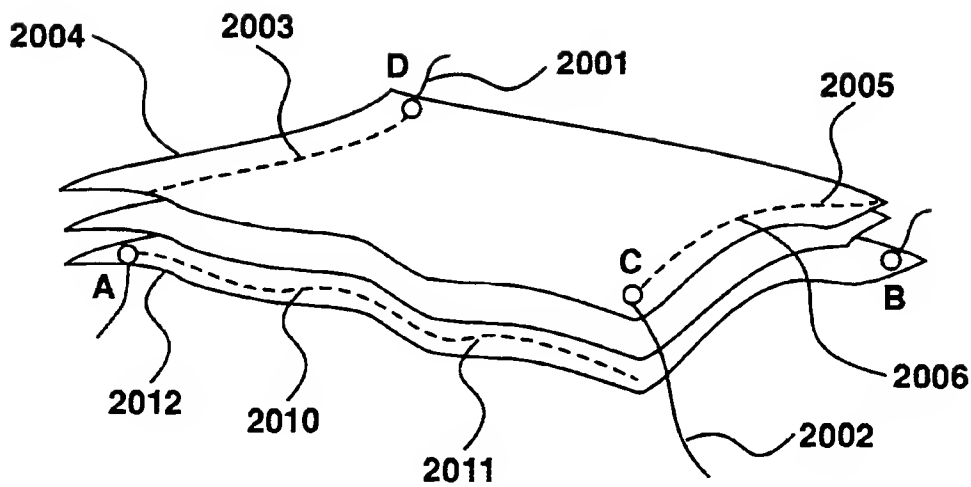


Figure 20

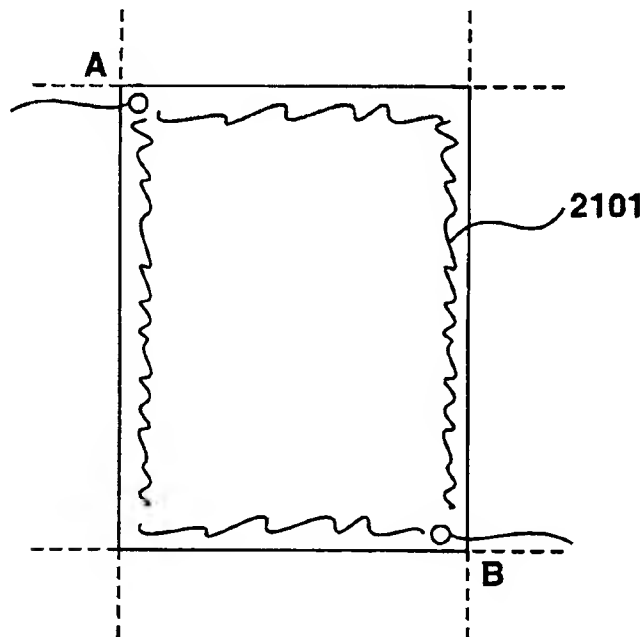


Figure 21

Detector Constructed From Fabric

5 The present invention relates to a detector constructed from fabric having electrically conductive elements to define at least two electrically conducting planes.

A fabric touch sensor for providing positional information is described in United States patent 4,659,873 of Gibson. The sensor is fabricated using two layers of fabric having conducting threads, separated by a resistive layer to prevent unintentional contact.

10 An improvement to this known configuration is proposed in the applicant's co-pending British patent application number 98 20 902 in which there is provided a position detector constructed from fabric having electrically conductive elements, comprising at least two electrically
15 conductive planes. A potential is applied across at least one of the planes to determine the position of a mechanical interaction. In addition, a second electrical property is determined, such as current, to identify additional properties to the mechanical interaction, such as an applied force, an applied pressure or an area of contact.

20 A further proposal is included in the applicant's co-pending British patent application number 98 20 905 in which there is provided a detector constructed from fabric having electrically conductive elements defining at least two electrically conductive planes and configured to produce electrical
25 outputs in response to mechanical interactions. At least one of the planes includes first portions and second portions, wherein the first portions have a higher resistance than the second portions and the first higher resistance portions are more flexible than the second portions.

30 A third proposal is described in the applicant's co-pending British patent application number 98 20 906, in which there is provided a detector constructed from fabric having electrically conductive elements and configured to produce electrical outputs in response to mechanical

interactions. The detector surface is divided into a plurality of regions and each of these regions includes a first conducting plane and a second conducting plane. A mechanical interaction results in conducting planes of at least one of said regions being brought closer together. A fourth proposal is described in the applicant's co-pending British patent application (ETC-P104-GB) in which there is provided a fabric constructed from a electrically conducting fibres and from electrically insulating fibres by a mechanical process. Electrical connection means are connected to electrically conducting fibres of the fabric during the mechanical process. Thus, the fourth improvement provides for securely attaching electrical connectors to electrically conducting fibres, thereby reducing the risk of said connectors becoming detached during use of the detector.

A problem with the known touch sensor described in the aforesaid US patent of Gibson is that relationships between measured voltages and location can become very non-linear, particularly towards the edges of the detector. This in turn may lead to a requirement for complex linearisation circuitry and ultimately a loss of spatial definition.

According to a first aspect of the present invention, there is provided a detector constructed from fabric having electrically conductive elements to define at least two electrically conducting planes and configured to produce an electrical output in response to a mechanical interaction, wherein a conductivity non-uniformity is included in at least one of said planes so as to modify an electrical response to a mechanical interaction.

In a preferred embodiment, the conductivity non-uniformity includes a co-operating pair of conducting strips configured to generate a substantially linear electric field within the conducting planes. Preferably, the strips are applied to each of the conducting planes at orthogonal locations.

According to an alternative preferred embodiment, all edges of the conducting planes are modified. The conductivity non-uniformity may be defined by adjusting the density of conducting threads or it may be created

by printing conductive materials onto the detector.

According to a second aspect of the present invention, there is provided a method of constructing a detector from fabric having electrically conductive elements to define at least two electrically conducting planes and configured to produce an electrical output in response to a mechanical interaction, comprising the step of introducing a conductivity non-uniformity in at least one of said planes so as to modify an electrical response to a mechanical interaction.

The invention will be described by way of example only, with reference to the accompanying drawings of which:

Figure 1 shows a position detector constructed from fabric;

Figure 2 shows a control circuit identified in *Figure 1*;

Figure 3 details operations performed by the micro-controller identified in *Figure 2*;

Figure 4 details planes identified in *Figure 1*;

Figure 5 details current flow due to mechanical interaction;

Figure 6 details an alternative construction for conducting fabric planes;

Figure 7 shows an alternative configuration of conducting planes;

Figure 8 shows an alternative configuration of conducting planes;

Figure 9 details a composite configuration of conducting planes; and

Figure 10 shows an asymmetric object interacting with conducting planes.

Figure 11A and *Figure 11B* show an alternative construction for a detector;

Figure 12A and *Figure 12B* show a further alternative construction;

Figure 13 shows a further alternative construction;

Figure 14 shows a further alternative construction.

Figure 15 shows an alternative embodiment having a plurality of detectors;

Figure 16 shows an alternative detector configuration; and

Figure 17 shows multiple detectors of the type shown in *Figure 16*.

Figure 18 shows a first embodiment in which a connector has been included during the machining process; and

5 *Figure 19* shows an alternative embodiment in which a connector has been added during a machining process.

Figure 20 shows a detector constructed from fabric having a conductivity non-uniformity; and

10 *Figure 21* shows an alternative embodiment with a conductivity non-uniformity.

A position detector 101 constructed from fabric is shown in *Figure 1*. The detector has two electrically conducting fabric planes, in the form of a first plane 102 and a second plane 103. The planes are separated from each other and thereby electrically insulated from each other, by means of an
15 insulating mesh 104. When force is applied to one of the planes, the two conducting planes are brought together, through the mesh 104, thereby creating a position at which electrical current may conduct between planes 102 and 103. In this way, it is possible to identify the occurrence and/or position of a mechanical interaction.

20 The fabric planes are defined by fabric structures, which may be considered as a woven, non-woven (felted) or knitted etc. The fabric layers may be manufactured separately and then combined to form the detector or the composite may be created as part of the mechanical construction process.

25 When a voltage is applied across terminals 107 and 108, a voltage gradient appears over plane 102. When a mechanical interaction takes place, plane 103 is brought into electrical contact with plane 102 and the actual voltage applied to plane 103 will depend upon the position of the interaction. Similarly when a voltage is applied between connectors 111 and 112, a
30 voltage gradient will appear across plane 103 and mechanical interaction will

result in a voltage being applied to plane **102**. Similarly, the actual voltage applied to plane **102** will depend upon the actual position of the interaction. In this way, for a particular mechanical interaction, it is possible to identify locations within the plane with reference to the two aforesaid measurements.

5 Thus, connectors **107**, **108**, **111** and **112** are received by a control circuit **121**, configured to apply voltage potentials to the detector **101** and to make measurements of electrical properties in response to mechanical interactions.

Control circuit **121** identifies electrical characteristics of the sensor **101** and in response to these calculations, data relating to the characteristics of the environment are supplied to a data processing system, such as a
10 portable computer **131**, via a conventional serial interface **131**.

Control circuit **121** is detailed in *Figure 2*. The control circuit includes a micro-controller **201** such as a Philips 80C51 running at a clock frequency of twenty megahertz. Operations performed by micro-controller **201** are effected
15 in response to internally stored commands held by an internal two kilobyte read-only memory. The micro-controller also includes one hundred and twenty-eight bytes of randomly accessible memory to facilitate intermediate storage while performing calculations. Micro-controller **201** includes a serial interface **202** in addition to assignable pins and an interface for
20 communicating with an analogue to digital converter **203**, arranged to convert input voltages into digital signals processable by the micro-controller **201**.

The control circuit **121** includes two PNP transistors **211** and **212**, in addition to four NPN transistors **213**, **214**, **215** and **216**. All of the transistors are of relatively general purpose construction and control switching
25 operations within the control circuit so as to control the application of voltages to the position detector **101**.

In operation, measurements are made while a voltage is applied across first plane **102** and then additional measurements are made while a voltage is applied across the second plane **103**; and output voltage only
30 being applied to one of the planes at any particular time. When an output

voltage is applied to one of the planes, plane **102** or plane **103**, input signals are received from the co-operating plane **103** or **102** respectively. Input signals are received by the analogue to digital converter **203** via a selection switch **221**, implemented as a CMOS switch, in response to a control signal
5 received from pin C6 of the micro-controller **201**. Thus, in its orientation shown in *Figure 2*, switch **221** has been placed in a condition to receive an output from a first high impedance buffer **222**, buffering an input signal received from plane **102**. Similarly, when switch **221** is placed in its alternative condition, an input is received from a second high impedance
10 buffer **223**, configured to receive an input signal from plane **103**. By placing buffers **222** and **223** on the input side of CMOS switch **221**, the switch is isolated from high voltage electrostatic discharges which may be generated in many conditions where the detector undergoes mechanical interactions.

In the condition shown in *Figure 2*, switch **221** is placed in its upper
15 condition, receiving input signals from buffer **222**, with output signals being supplied to the second plane **103**. Further operation will be described with respect to this mode of operation and it should be appreciated that the roles of the transistor circuitry is reversed when switch **221** is placed in its alternative condition. As previously stated, condition selection is determined
20 by an output signal from pin C6 of micro-controller **201**. In its present condition the output from pin C6 is low and switch **221** is placed in its alternative configuration when the output from pin 6 is high.

Output pin C0 controls the conductivity of transistor **211** with pins C1 to C5 having similar conductivity control upon transistors **212**, **213**, **214**, **215**
25 and **216** respectively.

Transistors **211** and **213** are switched on when a voltage is being applied to the first plane **102** and are switched off when a voltage is being applied to the second plane **103**. Similarly, when a voltage is being applied to the second plane **103**, transistors **212** and **215** are switched on with
30 transistors **211** and **213** being switched off. In the configuration shown in

Figure 2, with switch 221 receiving an input from buffer 222, output transistors 211 and 213 are switched off with output transistors 212 and 215 being switched on. This is achieved by output pin C0 being placed in a high condition and pin C1 being placed in a low condition. Similarly, pin C3 is placed in a low condition and pin C4 is placed in a high condition.

In the configuration shown, C3 is placed in a low condition, as previously described. The micro-controller 201 includes a pull-down transistor arranged to sink current from the base of transistor 212, resulting in transistor 212 being switched on to saturation. Consequently, transistor 212 appears as having a very low resistance, thereby placing terminal 111 at the supply voltage of five volts. Resistor 231 (4K7) limits the flow of current out of the micro-controller 201, thereby preventing burn-out of the micro-controller's output transistor.

Pin C4 is placed in a high state, resulting in transistor 215 being placed in a conducting condition. A serial resistor is not required given that the micro-controller 201 includes internal pull-up resistors, as distinct from a pull-up transistor, such that current flow is restricted. Thus, transistors 212 and 215 are both rendered conductive, resulting in terminal 111 being placed at the positive supply rail voltage and terminal 112 being placed at ground voltage. The capacitors shown in the circuit, such as capacitor 219, limit the rate of transistor transitions thereby reducing rf transmissions from the sensor 101.

With transistors 212 and 215 placed in their conductive condition, input signals are received from the first plane 102 in the form of a voltage applied to terminal 108. For position detection, this voltage is measured directly and transistor 214 is placed in a non-conductive condition by output pin C2 being placed in a low condition. Under these conditions, the voltage from input terminal 108 is applied to analogue to digital converter 203 via buffer 222 and switch 221.

In accordance with the present invention, a second electrical property is determined which, in this embodiment, represents the current flowing through the sensor in response to a mechanical interaction. The current measurement is made by placing transistor **215** in a conductive condition, by placing output pin **C4** in a high condition. In this condition, current received at terminal **108** is supplied to transistor **214** via resistor **214A**, having a resistance of typically 5k selectable so as to correspond to the characteristics of the sensor. A voltage is supplied to A to D converter **203** via buffer **222** and switch **221** but on this occasion the voltage represents a voltage drop, and hence a current, across resistor **214A**.

Thus, transistors **212** and **215** are placed in a conducting condition, transistor **214** is placed in a non-conducting condition, so as to measure voltage, and is then placed in a conducting condition so as to measure current. The roles of the transistors are then reversed, such that output transistors **211** and **213** are placed in a conducting condition, with transistors **212** and **215** being placed in a non-conducting condition (and switch **221** reversed) allowing a voltage to be measured by placing transistor **216** in a non-conducting condition, and then allowing a current to be measured by placing transistor **216** in a conducting condition.

The cycling of line conditions, in order to make the measurements identified previously, is controlled by a clock resident within micro-controller **201**. After each condition has been set up, a twelve bit number is received from the digital to analogue converter **203** and this number is retained within a respective register within micro-controller **201**. Thus, after completing a cycle of four measurements, four twelve bit values are stored within the micro-controller **201** for interrogation by the processing device **131**. Furthermore, the rate of cycling may be controlled in response to instructions received from the processing device **131**.

Operations performed by micro-controller **201** are detailed in *Figure 3*. The micro-controller continually cycles between its four configuration states

and each time a new input is produced, representing a current or a voltage in one of the two configurations, new output data is calculated on an on-going basis. Thus, output registers are updated such that the best data is made available if the micro-controller is interrupted by the external processor 131.

5 The micro-controller 201 is fully interrupt driven in terms of receiving external interrupts for data interrogation along with internal interrupts in order to initiate a configuration cycle. The external interrupt has a higher priority such that external processor 131 is provided with information as soon as possible in response to making an interrupt request.

10 Internally interrupts for the micro-controller 201 are generated by its own internal timer and the procedure shown in *Figure 3* is effectively held in a wait state until a next timer interrupt is received at step 301. The wait state allows voltage levels on connections 107, 108, 111 and 112 to become stable and provides sufficient time for valid data to be received from the analogue to digital converter 203.

15 At step 302, an output is received from analogue to digital converter 203 and at step 303 calculations are performed with respect to the most current data received from the analogue to digital converter, so as to convert numerical values relating to voltages and currents into numerical values representing properties of the mechanical interaction. Thus, after performing calculations at step 303, appropriate registers are updated at step 304 and it is these registers that are interrogated in response to an interrupt received from processing system 131.

20 At step 305 next conditions for the output lines are set by appropriate logic levels being established for output pins C0 to C6. After the next output condition has been selected, the processor enters a wait state at step 306, allowing the electrical characteristics to settle, whereafter processing continues in response to the next timer interrupt.

25 Thus, it should be appreciated that on each iteration of the procedure shown in *Figure 3*, one of the output conditions is selected at step 305. Thus,

30

it should be appreciated that the input data is effectively delayed and does not represent a condition of the electrical characteristics at an instant. If in practice, the delay between measurements becomes too large, it becomes necessary to enhance the frequency of operation of circuits within the control system shown in *Figure 2*. Thus, the rate of conversion for converter 203 would need to be increased and the circuitry would need to be redesigned for high frequency operation. This in turn could create problems in terms of high frequency interference resulting in enhanced shielding being required for the facility as a whole.

When output condition number one is selected, an output voltage at 108 is determined. On the next cycle, identified as output condition number two, the current flowing through connector 108 is determined. On the next iteration, under output configuration number three, the voltage appearing at connector 112 is determined and on the next cycle, identified as condition number four, the current flowing through connector 112 is determined. After each of these individual measurements, new data is generated in response to steps 303 and 304 such that resulting output registers are being regularly updated on a continual basis, such that the processing system 131 may effectively perform a continual monitoring operation in terms of changes made to the mechanical interactions with the detector 101.

In a typical implementation, the four characteristic measurements, making up a complete cycle, will be repeated at a frequency of between twenty-five to fifty times per second. In situations where such a repetition rate is not required, it may be preferable to increase the duration of the wait states and thereby significantly reduce overall power consumption.

Planes 102, 103 and 104 of the detector 101 are detailed in *Figure 4*. Planes 101 and 103 are of substantially similar construction and are constructed from fabric having electrically conductive elements 402 in plane 102 along with similar electrical conductive elements 403 in plane 103. Thus, it is possible for a voltage indicative of position to be determined when

conductive elements **402** are placed in physical contact with conductive elements **403**.

The overall resistivity of planes **402** and **403** are controlled by the inclusion of non-conducting elements **404** and **405**. Thus, resistivity is controlled by controlling the relative quantities and/or densities of conductive elements **402** with non-conductive elements **404**. Resistivity may also be controlled by selecting an appropriate fibre type, adjusting the thickness of the fibre or adjusting the number of strands present in a yarn.

Plane **404** represents a non-conducting insulating spacer positioned between the two conducting planes **102** and **103**. Plane **104** is constructed as a moulded or woven nylon sheet having an array of substantially hexagonal holes **411**, the size of holes **411** is chosen so as to control the ease with which it is possible to bring conductive elements **402** into physical contact with conductive elements **403**. Thus, if relatively small holes **411** are chosen, a greater force is required in order to bring the conductive elements together. Similarly, if the size of the hole is increased, less force is required in order to achieve the conductive effect. Thus, the size of holes **411** would be chosen so as to provide optimal operating conditions for a particular application. Operating conditions may also be adjusted by controlling the thickness of layer **104**, its surface flexibility and the contour of co-operating planes **102** and **103**.

When a potential is applied across one of the conducting planes, the actual potential detected at a point on that plane will be related to the position at which the measurement is made. Thus, a direct voltage measurement from the co-operating plane gives a value from which a positional co-ordinate may be determined. By reversing the plurality of the planes and taking a measurement from the opposing plane, two co-ordinates are obtained from which it is then possible to identify a precise location over the planar surface.

In addition to measuring position on the planar surface, the present invention is directed at identifying additional electrical properties in order to

determine properties of the mechanical interaction. As previously described, the system is configured to measure currents in addition to measuring voltages.

When the two conducting planes are brought into mechanical contact, due to a mechanical interaction, the amount of current flowing as a result of this contact will vary in dependence upon the actual position of the plane where the mechanical interaction takes place. The position of the mechanical interaction has also been determined with reference to voltages and it could be expected that these two quantities will vary in a substantially similar way, each representing the same physical situation. Experience has shown that variations in measured current do not follow exactly the same characteristic as variations in measured voltage. As illustrated in *Figure 5*, the amount of current flowing due to a mechanical interaction will depend upon the position of a mechanical interaction 501. However, in addition to this, the amount of current flow will also depend upon the size of the mechanical interaction. As the size of the mechanical interaction increases, there is a greater area of contact and as such the overall resistance of the mechanical interaction is reduced. However, it should be appreciated that variations in terms of current with respect to interaction size is a sophisticated relationship, given that, in addition to the resistivity of the contact area 501, the resistivity of the actual electrical connections within the sheet must also be taken into account.

Thus, current is transmitted through a region 502 in order to provide a current to the contact region 501. Some aspects of this effect will be compensated with reference to position calculations and other variations due to this effect may be compensated by a non-linear analysis of the input data.

Contact area resistivity is illustrated generally at 510 and shows that the amount of current flowing between plane 102 and plane 103 is considered as being related to the area of mechanical interaction, which is related to the area of contact externally and to the level of externally applied mechanical force.

The resulting non-linear relationship between the force area product and the resulting current flow is illustrated generally at 520. At 521 there is an initial threshold point, identifying the point at which the gap starts to be closed, followed by an operational part of the curve which may give useful indications of pressure up to point 522, whereafter the relationship becomes very non-linear until position 523 where the relationship effectively saturates.

Using a detector of the type illustrated in *Figure 1*, it is possible to measure current flow, which could also be considered as contact resistance, in order to identify an additional mechanical property of the interaction. As illustrated in *Figure 5*, this other mechanical property is related to the area of contact between the sheets, determined by the amount of force applied to the sheets, and to the total area over which the force is applied; or a combination of these two properties. Thus, data relating to force and area may give useful information relating to the interaction, separate from the position at which the interaction takes place.

In some situations, such as when using a stylus or similar implement, the area of applied force remains substantially constant therefore a measurement of current will enable calculations to be made in terms of stylus pressure. Pressure sensitive styli are known but in known configurations the pressure detection is determined within the stylus itself, leading to the stylus being mechanically connected to operational equipment or requiring sophisticated wireless transmission within the stylus itself. The present embodiment allows stylus pressure to be determined using any non-sophisticated stylus, given that the pressure detection is made by the co-operating fabric detector, arranged to detect stylus position (with reference to voltage) in combination with stylus pressure, with reference to current.

An alternative construction for the conducting fabric planes is illustrated in *Figure 6*. The detector includes a first conducting plane 601 and a second conducting plane 602. In addition, woven into each of the conducting planes 601 and 602, there are a plurality of non-conducting nodes

605 arranged to mutually interfere and thereby separate the two conducting planes. Between the nodes, the fabrics of the first and second planes may be brought into contact relatively easily such that the application of force, illustrated by arrow 611 would tend to cause a finite number of regions interspersed between nodes 605 to be brought into contact. Thus, for a particular region, contact either is taking place or is not taking place as illustrated by curve 621.

With a number of such regions brought into contact, the overall level of current flow will tend to vary with the area of contact as illustrated by curve 631. Thus, using a construction of the type shown in *Figure 6*, it is possible to obtain a more linear relationship, compared to that shown in *Figure 5*, in which the level of current flow gives a very good indication of the area of coverage as distinct from the level of force applied to the mechanical interaction.

Given a construction of the type shown in *Figure 6*, an indication of applied force or pressure may be obtained, in addition to an accurate determination of area, by providing an incremental switching operation. In the configuration shown in *Figure 7*, there is provided a first conducting plane 701 which interacts with a second conducting plane 702. Furthermore, conducting plane 702 interacts with a third conducting plane 704. Conducting plane 701 is separated from conducting plane 702 by non-conducting portions 705. Similarly, plane 702 is separated from plane 704 by non-conducting portions 706. More non-conducting portions 705 are provided than similar non-conducting portions 706. Consequently, less force is required to produce electrical contact between planes 701 and 702 than is required to produce an electrical contact between planes 702 and 704. In this way, it is possible to provide an incremental measurement of force, given that a low force will only cause contact between plane 701 and plane 702 whereas a larger force will also provide electrical contact between plane 702 and 704.

An alternative configuration is shown in *Figure 8* in which it is possible to obtain enhanced substantially continuous variations in current flow with respect to applied force. A first conducting plane **801** interacts with a second conducting plane **802**. The planes are woven in such a way as to produce very uneven surfaces such that, under light load, the level of interaction is relatively low. As load increases, as illustrated generally at **805**, a greater level of surface contact shown at **806** is created thereby increasing the level of current flow in a substantially continuous way. It should also be noted that this configuration does not include an insulating layer as such and that a level of current flow will always take place even under conditions of zero load. Alternatively, a very thin insulating layer could be provided, having a relatively low threshold, thereby resulting in a zero current flow when no load is applied.

As shown by curve **811**, the output current varies with respect to variations in applied force for a constant load area. Similarly, as shown by curve **821**, output current varies with respect to load area for a substantially constant applied force.

A composite configuration is shown in *Figure 9*, in which a detector **901**, substantially similar to that shown in *Figure 6*, is combined with a detector **902**, substantially similar to that shown in *Figure 9*. Detector **901** provides an accurate measurement of applied area and it is relatively unaffected by applied force. Detector **902**, as shown in *Figure 8*, provides an output which varies with respect to area and force. Thus, by processing the output of these two detectors in combination, it is possible to compensate the output from detector **902** in order to produce values representing force, such that the two currents provide indications of both force and area.

The operation of the control circuit **121** is such as to apply a first voltage across diagonals **107** and **108** with a similar voltage being applied across diagonals **111** and **112**. The nature of the voltage distribution is therefore asymmetric, but this does not result in difficulties provided that the

area of contact between the two planes is relatively symmetric. However, should an asymmetric area of contact be made, as illustrated in *Figure 10*, differences will occur in terms of current measurements when considering calculations made in the two directions.

5 An asymmetric object **1001** is shown applied to the surface of a detector **1002**. When a voltage is applied between contact **107** and **108**, paths over which current may flow, illustrated generally at **1003** are relatively large and the object is perceived as having a large area or is perceived as applying a large force. In the opposite dimension, when a voltage is applied
10 between **111** and **112**, the regions over which current flow takes place illustrated generally at **1105**, become relatively smaller therefore the object would be perceived as having a relatively smaller area or would be perceived as providing a relatively smaller force.

 If the system is programmed to the effect that the object has a
15 constant area and applies a constant force, these differences in terms of current flow may be processed in order to give an indication as to the orientation of the object. Thus, the system of the type illustrated in *Figure 10*, is used in combination with the detector of the type illustrated in *Figure 9* it is possible to make reference to the parameters of location in two-dimensions,
20 force or pressure, the area of application and orientation.

 In the preferred embodiment, electrical characteristics of voltage and current are measured. Alternatively, it would be possible to determine the resistance or the resistivity of the conducting sheets. Problems may be encountered when using alternating currents due to energy being radiated
25 from the conducting sheets. However, in some situations it may be preferable to use alternating currents, in which further electrical characteristics of the detector may be considered, such as capacitance, inductance and reactance etc.

 The detector shown in *Figure 1*, constructed from conducting planes
30 **102** and **103**, operates satisfactorily if the plane of the detector is maintained

substantially flat. This does not create a problem in many applications where relatively flat operation is considered desirable. However, although constructed from fabric, thereby facilitating bending and folding operations, the reliability of the detector in terms of its electrical characteristics cannot be guaranteed if the detector planes are folded or distorted beyond modest operational conditions.

A detector is shown in *Figure 11*, constructed from fabric having electrically conductive elements to define at least two electrically conductive planes. The detector is configured to produce an electrical output in response to a mechanical interaction, as illustrated in *Figure 1*. At least one of the planes includes first portions and second portions in which the first portions have a higher resistance than said second portions and the first higher resistance portions are more flexible than the second portions. In this way, flexing occurs at the portions of high resistance, where contact between the planes has little effect, while the lower resistance portions, where contact does have a strong electrical effect, remain substantially rigid such that the flexing of the material does not occur over these portions of the detector.

Portions 1101 have a relatively high resistance compared to portions 1102. Portions 1101 are not involved in terms of creating an electrical reaction in response to a mechanical interaction. The electrical responses are provided by the more rigid weave of portions 1102. The purpose of portions 1101 is detailed in *Figure 11B*. A curvature has been applied to the detector but the configuration is such that normal operation is still possible. The flexing has occurred predominantly at portions 1101. However, portions 1102 have remained straight thereby ensuring that they remain displaced from each other, even when a curvature is present, such that the detector is still available for detecting the presence of a mechanical interaction.

The rigidity of portions 1102 may be enhanced as shown in *Figure 12A*. A first plane 1201 has rigid portions 1202 and flexible portions 1203. A second plane 1204 has relatively rigid portions 1205 and relatively flexible

portions 1206. The relatively flexible portions 1206 physically contact against similar portions 1203 in the first plane 1201. In order to ensure that there is no, or at least minimal electrical interaction at these points of contacts, the electrical resistance of the flexible portions 1203 and 1206 is relatively high. A partially insulating layer may be provided between the conducting layers, as shown in *Figure 1*. However, the flexible portions 1203 act as insulating separators therefore in this embodiment the provision of a separation layer is not essential. Furthermore, the rigidity of the interacting sections, in terms of the rigid portions 1202 and 1205, has its rigidity further enhanced by the presence of relatively solid intermediate plates 1208.

Flexing of the construction shown in *Figure 12A* is substantially similar to that provided by the embodiment shown in *Figure 11B*. The flexing of the embodiment shown in *Figure 12A* is detailed in *Figure 12B*. Flexing occurs at the position of the relatively flexible portions 1203 and 1206. The rigidity of portions 1202 and 1205 is enhanced by the provision of more solid plates 1208. Thus, the embodiment shown in *Figures 12A* and *12B* may have more strenuous flexing forces applied thereto such that mechanical interaction detection is maintained even under severe operating conditions.

The provision of the flexible portions effectively provide lines over the surface of the conducting planes where folding is permitted. Thus, complex curvatures may be obtained by a number of folds being effected at a plurality of these preferred foldable lines, thereby allowing complex shapes to be attained while maintaining the desired electrical characteristics.

An alternative embodiment is shown in *Figure 13* in which a first co-operating plane has flexible high resistive portions 1301 and rigid conducting portions 1302. This plane co-operates with a second plane 1303 of substantially homogenous construction. Thus, sufficient flexing and insulation is provided by the non-conducting flexible portions 1301 of the lower co-operating plane 1304. The rigidity of conducting portions 1302 may be enhanced in a fashion substantially similar to that provided by *Figure 12A* as

illustrated in *Figure 14*. The device includes an outer plane **1401** of substantially homogenous conducting construction. Below this, there is provided a second co-operating plane **1402** and the two planes may be separated by an insulating layer not shown in the example. The second plane or layer includes flexible non-conducting portions **1403** and more rigid conducting portions **1404**, substantially similar to those shown in *Figure 13*. In addition, rigid plates **1405** are provided below each rigid portion **1404** thereby significantly enhancing the rigidity of these portions. Thus, the construction in *Figure 4* is capable of withstanding more aggressive working environments compared to the lighter construction shown in *Figure 13*.

In the construction shown in *Figures 13* and *14* the outer layers, **1303** and **1401** respectively, are fabricated in a substantially elastic fashion, thereby providing for a stretching or extension of this layer during flexing operations.

The detector shown in *Figure 1* is capable of accurately detecting the position of a mechanical interaction and as previously described, it is also possible to determine other characteristics of the mechanical interaction by modifying other electrical properties. A problem with the detector shown in *Figure 1* is that it experiences difficulties if more than one unconnected mechanical interaction takes place. If a first mechanical interaction were to take place and, simultaneously, a second mechanical interaction were to take place, displaced from the first, it would not be possible, using the configuration shown in *Figure 1*, to identify the presence of two mechanical interactions. A condition would be detected to the effect that a mechanical interaction is taking place but the system would tend to perceive this as a single mechanical interaction having characteristics substantially similar to the average of the characteristics of the two independent interactions.

An alternative embodiment for overcoming problems of this type is shown in *Figure 15*. In *Figure 15*, a plurality of detectors **1501**, **1502**, **1503**, **1504**, **1505**, **1506** and **1507** have been connected together and each of

these individual detectors has its own unique connectors **1511**, **1512**, **1513** and **1514**. In this way, each of the individual detectors may be connected to its own respective control circuit, such as circuit **121** shown in *Figure 1* or, in an alternative embodiment, a single control circuit of the type shown in *Figure 1* may be shared, using a switching arrangement, between all seven of the Individual combined detectors. In this way, each individual detector, such as detector **1501**, provides the same level of accuracy as the detector shown in *Figure 1*. However, if two or more mechanical interactions take place on different detector sections, it is possible to detect this condition and provide appropriate output responses. However, it is only possible to detect a plurality of mechanical interactions if these interactions take place on different sections and it is not possible for the embodiment shown in *Figure 15* to detect a plurality of interactions if these interactions take place on the same section.

In the arrangement shown in *Figure 15*, the detectors have been arranged in strips such that there is enhanced definition in the direction of arrow **1521** but the definition in the direction of arrow **1522** has not changed.

In the detector shown in *Figure 1*, position detection is made possible using four electrical connection cables, a first two connected to opposing diagonal corners of the upper sheet and a further two connected to the alternative opposing diagonal corners of the lower sheet. An alternative configuration is shown in *Figure 16* in which electrical connectors **1601**, **1602**, **1603** and **1604** are connected to respective corners **1611**, **1612**, **1613** and **1614** of a lower plane conducting sheet **1621**. An upper plane conducting sheet **1622** is connected to a single detecting cable **1631** connected at a position **1632** towards an edge of upper conducting sheet **1622**. A disadvantage of the configuration shown in *Figure 16* is that five separate electrical connections are required whereas only four electrical connections are required in the configuration shown in

Figure 1. However, in some circumstances, the configuration shown in *Figure 16* does have advantages over that shown in *Figure 1*.

The configuration shown in *Figure 16* may be used to effectively multiplex the operation of a detector so as to facilitate the detection of a plurality of mechanical interactions to a greater extent than the configuration shown in *Figure 15*. In particular, it facilitates detecting multiple mechanical interactions in both dimensions of the planar detector.

As shown in *Figure 17*, a lower planar sheet **1701** has connections **1702**, **1703**, **1704** and **1705** at each of its corners. Thus, sheet **1701** operates in a way which is substantially similar to the operation of sheet **1621** and all output voltages are generated within this sheet, either across diagonal **1702** to **1704** or across diagonal **1703** to **1705**, thereby giving a two-dimensional co-ordinate within the area of the sheet.

An upper planar sheet **1721** is divided into a plurality of portions. In the example shown, eight portions **1731** to **1738** are provided. Thus, the mechanical action results in conducting planes of at least one of said regions being brought into electrical interaction with the lower plane **1701**. Furthermore, if a mechanical interaction occurs at region **1731** and a second mechanical interaction occurs at region **1735** (for example) both of these mechanical interactions may be determined independently and an output to this effect may be generated by a processing system, such as system **131**.

In order to achieve the space division multiplexing provided by regions **1731** to **1738**, time division multiplexing of the electrical signals is performed in which, during each individual time slot, one individual region **1731** to **1738** is considered. This is achieved by each individual region **1731** to **1738** having its own respective electrical connector **1741** to **1748**. These connectors are preferably incorporated in to the structure of the sheet.

Control circuitry for the configuration shown in *Figure 17* requires modification compared to that shown in *Figure 2*. In particular, each of the eight output control lines **1741** is supplied to its own respective buffering amplifier, similar to amplifiers **2223** and **2223** and the output from each of these eight amplifiers is applied to appropriate switching devices, allowing one of eight inputs to be selected using a plurality of switches substantially similar to switch **2221**.

A complete scanning cycle consists of applying a voltage between input terminals **1702** and **1704**. An output is then considered from each individual output terminals **1741** to **1748**. The voltages are then reversed such that a voltage is applied between output terminals **1705** and **1703**. Each of the individual input terminals is then considered again so as to provide two-dimensional co-ordinates within each of the individual regions **1731** to **1748**. As described with respect to *Figure 2*, both voltages and currents may be considered in order to provide additional mechanically related information, such as pressure related information etc.

In the detector configuration shown in *Figure 1* and in alternative detector configurations, such as that shown in *Figure 15* and that shown in *Figure 16*, it is necessary to provide electrical connection between processing equipment and the detector fabric itself. Techniques for the addition of electrical connectors to current conveying fabrics are known. However, in the known techniques, continual wear and usage of the detector assembly often results in electrical connectors becoming disconnected from the material fabric, resulting in total system failure. It is therefore highly desirable to provide a system in which the electrical connector is held very securely to the material fabric itself so as to provide a robust system which does not become disconnected through continual use.

An improved approach to providing electrical connection to the electric current carrying conductors within the fabric is illustrated in *Figure 18*. Further modification is shown in *Figure 19*. In both of these systems, the fabric is

constructed from electrically conducting fibres and from electrically insulating fibres by a mechanical process, such as weaving or knitting. An improved electrical connection is achieved by connecting electrical connection devices to the electrically conducting fibres of the fabric forming the detector during the mechanical fabric generating process. Thus, in the embodiments shown in *Figure 18* and *Figure 19*, there is no requirement for adding connectors after a fabric has been created. The provision of a connector to the electric current carrying fibres is achieved during the actual mechanical process itself. Thus, for example, if the fibres are being produced by a knitting operation, part of this knitting operation involves procedures by which the electrical current carrying connector is actually included as part of the overall knit.

Fibres **1801** making up the weave are illustrated in *Figure 18*. A weaving procedure may be considered as generating woven fabric by traversing in the direction of arrow **1802**. At pre-programmed positions, or at manually selected positions, modifications are made to the weaving process to the effect that a connector **1803** is to be introduced.

In the example shown in *Figure 18*, connector **1803** is an insulation displacement connector (IDC) allowing an insulated wire to be connected in such a way that it is not necessary to remove the insulation from the wire, given that the insulation is effectively cut as the wire, illustrated by reference **1804** is inserted into the connector in the direction of arrow **1805**.

The weaving procedure is modified such that connector **1803** is included as part of the weave and is thereby held relatively firmly after the weaving procedure has been completed. In order to provide a further enhanced mechanical connection between electrical connector **1803** and the remaining woven fabric, additional layers of electrically conducting epoxy resin **1805** and **1806** are applied, such that, in operation, physical force applied to connector **1803** such that the connector will not, under normal circumstances, be displaced from the woven material of the device and will maintain electrical integrity.

A similar configuration is shown in *Figure 19* in which a rivet fastener 1901 is applied during a weaving or knitting process, thereby substantially embedding the rivet fastener within the overall weave or knit. After the rivet fastener has been secured by the woven fabric 1902, electrically conducting epoxy resin 1903 is applied to provide enhanced mechanical and electrical stability.

In the configuration shown in *Figure 1* and in the configuration shown in *Figure 16*, an electrical field is established over the transmitting plane. Given a plane of infinite size, the electrical field would have a regular geometric distribution and the position of a mechanical interaction could be determined from two voltage measurements in a substantially straightforward way. However, in the configuration shown in *Figure 1* and *Figure 16*, edges are present and these edges introduce severe distortions to the nature of the electric field from which measurements are being taken. In the control circuit 121 and within the data processing system 132 it is possible to provide a level of compensation, possibly in response to empirical measurements but such an approach has disadvantages, one of which being a loss of resolution.

Systems are shown in *Figures 20* and *21* in which a detector is constructed from fabric having electrically conductive elements to define at least two electrically conducting planes. The detector is configured to produce an electrical output in response to a mechanical interaction. The relationship between mechanical interaction and electrical output is enhanced by introducing a conductivity non-uniformity which is included in at least one of the planes so as to modify an electrical response to the mechanical interaction.

In *Figure 20*, an electrical connector 2001 is connected to a plane at a first corner and a second connector 2002 is connected to the diagonally opposing corner. A configuration of this type could be used for a detector of

the type shown in *Figure 1*, in which the electrical field effectively traverses across the diagonal corners, resulting in distortions at the edges. In the embodiment shown in *Figure 20*, a conducting thread **2003** with relatively low resistivity is included across edge **2004**, electrically connected to connector **2001**. Similarly, a second conducting thread **2005**, with relatively low resistivity, extends from electrical connection **2002** along edge **2006**. In this way, the whole of edge **2004** becomes conducting and the whole of edge **2006** becomes conducting. The resulting electric field is then substantially linear throughout the length of the detector thereby substantially eliminating non-linear edge effects.

In its co-operating plane **2010** a low resistance conducting thread **2011** is included along edge **2012** and a similar conducting thread is provided along the opposing edge. In this way, the electric field traverses in a direction which is orthogonal to the electric field provided in the upper sheet, thereby allowing co-ordinates defined in mutually orthogonal co-ordinate space.

A conducting material is shown in *Figure 21* in which areas **2101**, close to all four edges, have had their conductivity modified, such that the overall conductivity of the sheet is non-uniform. This modification to conductivity may be achieved in several ways, including the addition of a conducting thread of the type illustrated in *Figure 20*. Alternatively, the modification to conductivity, to provide conductivity non-uniformity, may be achieved by a printing operation in which electrically conducting inks, possibly including silicon, are printed at region **2101**. Alternatively, the density of conducting fibres in the woven material itself may be modified towards the edges of the detector, again resulting in a conductivity non-uniformity. Furthermore, it should be appreciated that modifications of this type may be achieved using combinations of the above identified effects in order to tailor the required level of non-uniformity for a particular application.

Claims

1. A detector constructed from fabric having electrically
conductive elements to define at least two electrically conducting planes and
5 configured to produce an electrical output in response to a mechanical
interaction, wherein

a conductivity non-uniformity is included in at least one of said planes
so as to modify an electrical response to a mechanical interaction.

10 2. A detector according to claim 1, wherein said conductivity non-
uniformity includes a co-operating pair of conducting strips configured to
generate a substantially linear electric field within said conducting planes.

15 3. A detector according to claim 2, wherein said strips are applied
to each of said conducting planes at mutually orthogonal locations.

4. A detector according to claim 1, wherein all edges of a
conducting plane are modified.

20 5. A detector according to claim 1, wherein said conductivity non-
uniformity is defined by adjusting the density of conducting threads.

6. A detector according to claim 1, wherein said conductivity non-
uniformity is created by printing conductive materials onto the detector.

25 7. A detector according to any of claims 1 to 6, wherein said
electrically conductive elements are constructed from a fabric having
electrically conducting fibres and electrically insulating fibres by a mechanical
process, wherein electrical connection means are connected to electrically
30 conducting fibres of said fabric during said mechanical process.

8. A fabric according to claim 7, wherein mechanical process is a knitting operation or a weaving operation and said connector is an insulation displacement connector.

5

9. A detector according to any of claims 1 to 6, having electrically conductive elements and configured to produce electrical outputs in response to mechanical interactions, wherein a detector surface is divided into a plurality of regions;

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each of said regions includes a first conducting plane and a second conducting plane; and

a mechanical interaction results in conducting planes of at least one of said regions being brought closer together.

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10. A detector according to any of claims 1 to 6, wherein at least one of said planes includes first portions and second portions, said first portions have a higher resistance than said second portions and said first higher resistance portions are more flexible than said second portions.

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11. A detector according to any of claims 1 to 6, wherein a potential is applied across at least one of said planes to determine the position of a mechanical interaction and said second electrical property is determined to identify additional properties of said mechanical interactions.

25

12. A detector according to claim 11, configured to measure current or resistance as said second electrical property and configured to determine applied force, applied pressure, area of contact or orientation of an object as the additional property of said mechanical interactions.

13. A method of constructing a detector from fabric having electrically conductive elements to define at least two electrically conducting planes and configured to produce an electrical output in response to a mechanical interaction, comprising the step of introducing a conductivity non-uniformity in at least one of said planes so as to modify an electrical response to a mechanical interaction.

14. A method of constructing a detector from fabric having electrically conductive elements according to claim 14, wherein said conductivity non-uniformity includes a co-operating pair of conducting strips configured to generate a substantially linear electric field within said conducting planes.

15. A method according to claim 14, wherein said strips are applied to each of said conducting planes at mutually orthogonal locations.

16. A method according to claim 13, wherein all edges of a conducting plane are modified.

17. A method according to claim 13, wherein said conductivity non-uniformity is defined by adjusting the density of conducting threads.

18. A method according to claim 13, wherein said conductivity non-uniformity is created by printing conductive materials onto the detector.

19. A method according to any of claims 13 to 18, wherein said electrically conductive elements are constructed from a fabric having electrically conducting fibres and electrically insulating fibres by a mechanical process, wherein electrical connection means are connected to electrically conducting fibres of said fabric during said mechanical process.

20. A method according to any of claims 13 to 18, wherein said planes have electrically conductive elements and are configured to produce electrical outputs in response to mechanical interactions, wherein a detector surface is divided into a plurality of regions;

each of said regions includes a first conducting plane and a second conducting plane; and

a mechanical interaction results in conducting planes of at least one of said regions being brought closer together.

21. A detector constructed from fabric having electrically conductive elements substantially as herein described with reference to *Figures 20 and 21*.

22. A method of constructing a detector from fabric having electrically conductive elements substantially as herein described with reference to *Figure 20 or Figure 21*.



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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): G1N (NACH, NACNR, NAEPR, NAGB8, NAGB10, NAGBR, NAQB),
H1N (NUJD)

Int Cl (Ed.7): G01L 1/20, G06K 11/12, 11/16

Other: ONLINE : WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
Y	EP 0032013 A1 (MOORE BUSINESS FORMS)	1,2,4, 6,13,14, 16,18
Y	US 4659873 (GIBSON et al)	1,2,4, 6,13,14, 16,18

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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